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Exposure of Waterfowl to Lead: A Nationwide Survey of Residues in Wing Bones of Seven Species, 1972–73

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Abstract

Wing bones of 4,190 ducks of seven species collected in 1972 and 1973 were analyzed for lead to provide a base line for lead burdens and to determine geographic patterns of lead exposure in these species. Lead residues ranged from trace amounts (< 0.5 ppm) to 361 ppm and reflected the history of exposure to lead from ingested shotshell pellets and other sources. Wing bones of mottled ducks (*Anas fulvigula*) contained the highest levels of lead, and those of lesser scaup (*Aythya affinis*) the lowest. Residues in redheads (*Aythya americana*), black ducks (*Anas rubripes*), mallards (*Anas platyrhynchos*), canvasbacks (*Aythya valisineria*), and pintails (*Anas acuta*) were intermediate. Wing bones of adults contained higher residues than did those of immatures. Levels were lower in birds from the Central Flyway than in those from the other flyways. The median lead level for immature mallards was considerably higher for birds from the Atlantic Flyway than for those from the Pacific and Mississippi flyways, although the proportions of birds with elevated lead levels (> 20.0 ppm) were roughly equal in all three flyways.

Lead poisoning has been recognized as a cause of waterfowl mortality since the turn of the century. Each year, 2 million waterfowl hunters expend more than 3,000 tons (2,700 metric tons) of lead shot. Many of these spent shot are eaten by birds as if they were seeds or grit. Poisoning occurs when the shot is ground down in the gizzard, dissolved by gastric juices, and absorbed by body tissues. Ducks that ingest lead shot experience physiological disturbances of the digestive, circulatory, and nervous systems that may eventually result in death. Lead poisoning affects most species of ducks, geese, and swans.

The number of deaths due to lead poisoning in wild duck populations has not been directly measured, although evidence suggests that the numbers are relatively high in several species. On the basis of incidence of shot in gizzards, studies of survival rates of birds dosed with lead shot, and reported die-offs, Bellrose (1959) estimated annual nationwide losses due to lead poisoning at 2 to 3% of the fall population of all waterfowl.

We provide the results of a survey initiated in 1972

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by the U.S. Fish and Wildlife Service to estimate exposure of several species of waterfowl to lead by examination of lead levels in their wing bones and to determine geographic variations in lead burdens of selected species. Wing bones were selected because they were readily obtainable from waterfowl wings collected each year from hunters by the Service.

Methods

Wings used for lead analysis were randomly selected from the Service's waterfowl wing survey collections of 1972 and 1973. Waterfowl wings are collected annually from a sample of duck stamp purchasers who are asked to participate in this survey by the U.S. Fish and Wildlife Service. The collection is designed to be representative of the species, sex, and age composition of ducks bagged by hunters in the United States. Wings for lead analysis were segregated by species, age, and State; up to 75 wings of immatures and 25 wings of adults made up each sample.

Wings were sent to the Raltech Scientific Services, Inc., Madison, Wisconsin, where lead analyses were performed. All samples were kept frozen from the time of receipt from hunters until they were prepared for analysis. The radius-ulna of each wing was removed and all easily removable flesh was detached. About 20% of the samples were discarded because the bones were broken or obviously had been hit by a lead pellet, or a pellet was found in the muscle tissue near the bone. The bones were rinsed with deionized water, marked with a coded tag, and placed on a rubber mat in a dermestid beetle colony. When all flesh was gone, the bones were removed, again rinsed with deionized water, and dried to a constant weight at 100 C. Bones were then broken in half and weighed before ashing. Samples were ashed in a 500 C muffle furnace overnight.

The ashed samples were cooled and moistened with deionized water; 5 ml of concentrated nitric acid was added; the solution was taken to dryness on a hot plate, returned to the furnace at 500 C for 15 to 20 min, and then removed and cooled. After 7 ml of concentrated hydrochloric acid and about 5 ml of water were added to each sample, a watch glass was placed on each dish, and the sample heated to dissolve the nitrated ash. Later the condensate on the cooled watch glass was rinsed into the dish and the contents of the dish transferred into an acid-washed 25-ml volumetric flask, prepared to volume, and mixed for subsequent analysis by atomic-absorption spectrophotometry (for analytical methods, see Perkin-Elmer Corporation 1971).

The lead determinations were made by using an initial scanning procedure where the samples were compared to standards which contained a quantity of calcium, phosphorus, and hydrochloric acid equivalent to that in the samples. Conditions for reading by atomic-absorption spectrophotometry were similar to those indicated by the Perkin-Elmer Corporation (1971). A deuterium background corrector was used and readings were taken at a wavelength of 283.3 mm.

Samples that contained between 2.0 and 20 μg per ml were read directly on the spectrophotometer. Samples containing more than 20 μg of lead per ml were diluted and reassayed. Samples that contained less than 2.0 μg per ml were analyzed by the following extraction and concentration procedure: An appropriate aliquot of the sample was transferred to a 100-ml volumetric flask, and a solution of 10% hydrochloric acid was added to maintain a similar acid concentration in samples and standards. Deionized water was added to bring the volume of samples and standards to 25 ml. Then 10 ml of citrate solution (400 g citric acid and 300 ml water, adjusted to a pH of 2.5 to 3.0 with about 140 ml NH_4OH and diluted to 1 liter with water) was added and the solution was mixed. Next, two drops of Bromphenol Blue indicator (0.40 g Bromphenol Blue, 6 ml 0.1N NaOH, diluted to 100 ml with water) was added and the solution was mixed again. The samples were then neutralized with NH_4OH to a pH of 2.5 to 3.0 (color change was from yellow to yellow-green). One milliliter of the ammonium pyrrolidino dithiocarbamate solution (5 g ammonium pyrrolidino dithiocarbamate dissolved in 100 ml water and filtered) was added to the samples before they were mixed. After 5 min, 5.0 ml of methyl iso-butyl ketone (MIBK) was added to each flask and shaken vigorously for 1 min. The two phases were allowed to separate and deionized water was carefully added to bring the MIBK layer to the top of the neck of the flask. The samples were read as soon as possible after extraction.

Standards were carried through the same extraction procedure. The range of the standards depended on the levels of lead in the samples. Normally, 0.2-5.0 μg of lead per 100 ml were used.

We aspirated the MIBK from the standards or samples into the atomic-absorption spectrophotometer's flame, using care to avoid the water layer. MIBK was used as the aspirating solution between samples.

Duplicate analyses of samples were normally within 15% of the mean. Recoveries were from 92 to 103%. Results are presented as parts per million (ppm) lead on a dry-weight basis.

Since hunters submit either right or left wings for the Service's waterfowl harvest survey, we tested the assumption that lead residues were equal in both wings of a particular bird. We found that the average difference in lead concentration between right and left

wings of 10 adult canvasbacks was less than 1 ppm (Wilcoxen Ranked Sum Test: $P > 0.05$). Residues ranged from 2.6 to 24.0 ppm of lead in left wings ($\bar{X}$ = 12.6) and from 3.3 to 23.5 ppm in right wings ($\bar{X}$ = 13.2).

Young birds hatched during the current season (immatures) were the primary source of information because the period during which they could have been exposed to lead was brief; elevated residues in the bones of an immature duck is unquestionable evidence of exposure to lead during that year. This is not true for adults, however, because the loss of lead from bone is slow. Consequently, an elevated lead level in bones of an adult bird may represent exposure during a previous year. Most immature mallards were 6 to 7 months old when collected and were experiencing their first exposure to lead. Immatures of other species would tend to be slightly younger than the immature mallards.

Results

Wing bones of 4,190 waterfowl—3,492 collected in 1972 and 698 in 1973—representing seven species were analyzed for lead (Table 1). Mallards (*Anas platyrhynchos*) made up more than half of the total sample because they were abundant in the harvest and widely distributed. We analyzed wing bones of mallards from 26 States nationwide, of black ducks (*Anas rubripes*) from 5 States in the Atlantic Flyway, and of pintails (*Anas acuta*) from 7 States in the Central and Pacific flyways. Wing bones of lesser scaup (*Aythya affinis*), redheads (*Aythya americana*), and canvasbacks (*Aythya valisineria*) were analyzed from areas where sufficient numbers were available to make up an adequate sample. Mottled ducks (*Anas fulvigula*) were represented only by samples from Florida, Louisiana, and Texas. Of the total of 2,381 mallard wings, 404 were collected from specified zones in California, Oregon, and Washington during the 1973 hunting season.

Table 1. *Numbers of ducks of different species from which wing bones were analyzed for lead, 1972-73.*

Species	Immature	Adult	Total
Mallard	1,931	450	2,381
Black duck	270	45	315
Mottled duck	159	69	228
Pintail	437	151	588
Redhead	95	51	146
Canvasback	109	56	165
Lesser scaup	264	103	367
Total	3,265	925	4,190

Lead residues in the seven species of waterfowl collected (Table 2) were strongly skewed to the right and were not readily transformable to normal distributions. As a result, parametric statistics based on the normal distribution could not be applied. Means are provided, however, for making general comparisons with data provided by others. White and Stendell (1977) showed that the median (the midpoint of the data set) and percentage of the sample with lead residues exceeding 20.0 ppm were useful for indicating exposure to lead of waterfowl collected on national wildlife refuges. In their study, both of these statistics were positively correlated with the incidence of lead shot in the gizzards.

Interquartile ranges and percentages of the samples with only traces of lead (< 0.5 ppm) are also provided in Table 2. Such a trace amount of lead indicates that the bird has had little exposure. The interquartile range (in ppm) extends from the 25th to 75th percentile and gives a measure of variability for each sample. A sample with a high dispersion of values has a high interquartile range.

Wing bones of mottled ducks contained higher levels of lead than did those of the other six species (Fig. 1). Residues were similar in samples of immature mottled ducks from Florida, Louisiana, and Texas. They had the highest mean and median lead levels found in any species from any State. The wing bones of about 43% of immature and adult mottled ducks contained more than 20.0 ppm lead. In contrast, lesser scaup had the lowest overall lead residues; only 1 of 264 immatures and 1 of 103 adults contained more than 20.0 ppm. Redheads, black ducks, mallards, canvasbacks, and pintails contained intermediate concentrations.

Wing bones of immature mallards provide the best comparison of lead residues among flyways (Fig. 2). On the basis of median values, lead levels were highest in the Atlantic Flyway and lowest in the Central Fly-

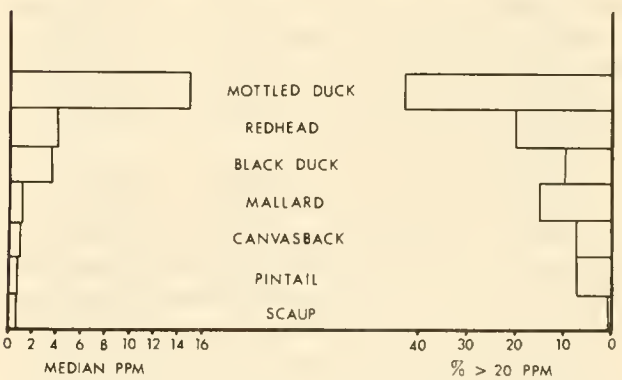

Fig. 1. Lead residues in wing bones of immature waterfowl of seven species, 1972-73.

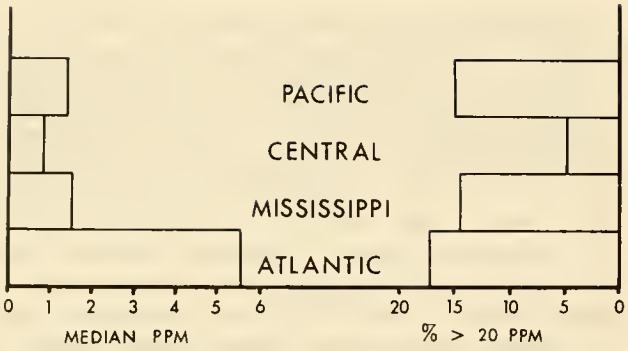

Fig. 2. Lead residues in wing bones of immature mallards from North American flyways, 1972-73.

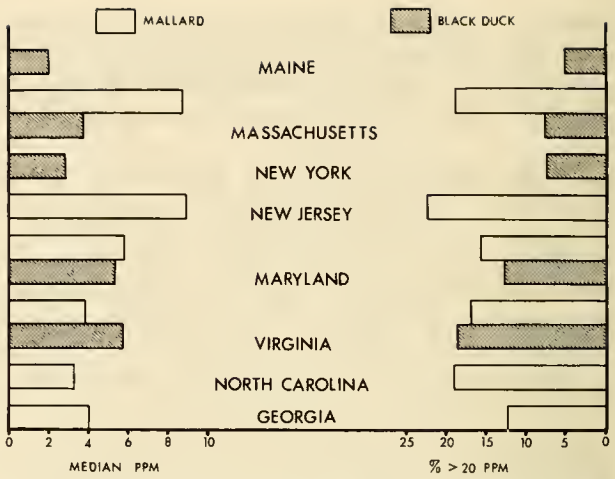

Fig. 3. Comparison of lead residues in wing bones of immature mallards and black ducks from the Atlantic Flyway, 1972.

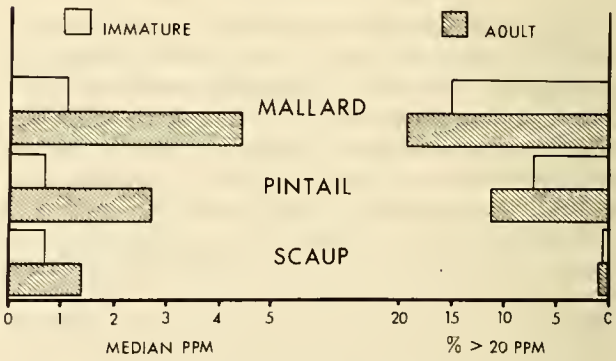

Fig. 4. Comparison of lead residues in wing bones of immature and adult mallards, pintails, and scaup, 1972-73.

way. Concentrations in the Mississippi and Pacific flyways were intermediate, but not much higher than those in the Central Flyway. The Atlantic Flyway also had the highest incidence of samples with more than 20.0 ppm of lead, and the Central Flyway had the lowest. Values for the Mississippi and Pacific flyways were only slightly lower than those for the Atlantic Flyway. About the same proportions of immature mallards from the Atlantic, Mississippi, and Pacific flyways contained elevated levels of lead. The median value for mallards from the Atlantic Flyway, however, was considerably higher than the medians for mallards from other flyways—indicating a higher incidence of wing bones containing intermediate concentrations of lead (5-20 ppm). Only 1.6% of the immature mallards from the Atlantic Flyway contained less than 0.5 ppm of lead, compared with 13.5% from the Mississippi Flyway, 32.9% from the Central Flyway, and 17.1% from the Pacific Flyway.

A comparison of median values in lesser scaup from each flyway indicated that those from the Atlantic Flyway were highest (although no samples contained more than 20.0 ppm lead), those from the Pacific Flyway were lowest, and those from the other two flyways were intermediate. About 37% of the scaup wing bones analyzed contained only trace levels of lead. Western pintails, redheads, and canvasbacks showed a pattern similar to that of mallards: lead residues were lower in birds from the Central Flyway than in birds from the Pacific Flyway.

In the Atlantic Flyway, black ducks generally contained lower lead residues than did mallards (Fig. 3). For black ducks, both median and percentage of samples with more than 20.0 ppm of lead increased from north to south (Maine to Virginia). This pattern was reversed for mallards. Birds from northern States had higher residues than birds from southern States.

Sample sizes of adults were small; however, nearly all bore higher lead residues than did immatures (Fig. 4). This is true of means, medians, and percentages of samples with more than 20.0 ppm of lead. Moreover, only 1.6% of the adult mallards contained only trace amounts (≤ 0.5 ppm) of lead, as compared with 15.4% of the immatures.

Subdivision of three Pacific Flyway States into zones provided an assessment of geographic patterns of lead exposure to immature mallards within those States (Table 3). Lead residues in birds from western Washington were higher than in those from eastern Washington, and higher in the Columbia River Basin of Oregon than in the rest of the State. (The Columbia River Basin includes the Sauvie Island Wildlife Management Area, an Oregon State waterfowl area with a history of high incidence of lead shot in waterfowl gizzards.)

Samples of immature mallards from three zones in California—Merced (lower Central Valley), Sacramento (upper Central Valley), and remainder of State

Table 2. *Residues of lead (ppm, dry weight) in wing bones of waterfowl collected nationwide in 1972 and in mottled ducks collected in Florida, Louisiana, and Texas in 1973.* (I = Immature; A = Adult)

Species, Flyway, and State	Life stage	Sample size	Statistic			Percent wings with	
			Mean (±SE)	Median (±SE)	Interquartile range	>20.0 ppm	<0.5 ppm
MALLARDS							
Atlantic							
Massachusetts	I	60	15.6 (2.7)	8.7 (1.5)	11.2	18.3	0.0
New Jersey	I	41	12.8 (1.8)	8.9 (2.3)	14.1	22.0	0.0
Maryland	I	55	10.0 (1.3)	5.8 (1.8)	13.3	16.4	1.8
Virginia	I	59	12.7 (3.3)	3.9 (1.8)	13.1	16.9	0.0
North Carolina	I	33	11.5 (2.8)	3.3 (2.5)	11.6	18.2	0.0
Georgia	I	64	9.1 (1.6)	3.9 (1.4)	11.2	12.5	6.3
Flyway total	I	312	11.9 (1.0)	5.6 (0.7)	12.9	17.0	1.6
Massachusetts	A	18	30.1 (4.3)	25.6 (4.8)	24.4	66.7	0.0
Maryland	A	18	13.8 (2.7)	9.8 (4.3)	19.9	38.9	0.0
North Carolina	A	19	9.9 (2.2)	7.3 (1.6)	7.3	10.5	0.0
Georgia	A	23	16.9 (3.3)	13.3 (4.3)	23.5	39.1	0.0
Flyway total	A	78	17.5 (1.8)	12.7 (2.4)	19.4	38.5	0.0
Mississippi							
Minnesota	I	61	7.4 (1.9)	0.7 (0.7)	5.1	13.1	34.4
Michigan	I	53	11.1 (3.3)	1.5 (1.0)	9.5	13.2	5.7
Illinois	I	57	7.2 (1.3)	2.3 (1.5)	12.1	10.5	5.2
Indiana	I	63	13.5 (3.4)	3.4 (1.6)	12.0	19.0	1.6
Ohio	I	61	10.7 (2.0)	2.8 (1.3)	12.2	19.7	6.6
Missouri	I	57	3.4 (1.0)	0.3 (0.2)	1.4	5.3	56.1
Kentucky	I	58	11.6 (2.0)	4.6 (1.6)	12.2	17.2	3.4
Tennessee	I	57	12.2 (2.3)	3.6 (1.7)	12.2	22.8	0.0
Arkansas	I	61	5.2 (1.4)	1.1 (0.3)	2.4	8.2	6.6
Louisiana	I	63	7.8 (2.2)	1.5 (0.3)	4.2	11.1	15.9
Flyway total	I	591	9.0 (0.7)	1.5 (0.2)	8.8	14.0	13.5
Minnesota	A	21	25.2 (11.7)	4.0 (3.9)	8.5	23.8	9.5
Michigan	A	18	15.5 (6.4)	5.6 (4.6)	10.7	16.7	0.0
Illinois	A	19	10.4 (1.8)	6.6 (2.8)	14.0	15.8	0.0
Ohio	A	21	12.2 (3.6)	5.3 (3.1)	12.0	14.3	0.0
Missouri	A	20	7.4 (1.9)	3.5 (2.9)	9.0	15.0	0.0
Kentucky	A	20	17.1 (6.5)	5.3 (3.5)	18.3	30.0	0.0
Tennessee	A	20	9.5 (2.5)	4.7 (3.4)	13.0	20.0	5.0
Arkansas	A	21	8.7 (2.2)	5.0 (2.0)	10.1	9.5	0.0
Louisiana	A	17	5.4 (1.4)	3.0 (1.4)	3.7	0.0	0.0
Flyway total	A	177	12.5 (1.8)	4.9 (0.6)	10.8	16.4	1.7
Central							
North Dakota	I	55	2.8 (1.1)	0.3 (0.0)	0.4	3.6	58.2
Nebraska	I	58	3.6 (1.2)	0.3 (0.1)	0.8	6.9	53.4
Colorado	I	56	4.0 (0.9)	1.3 (0.3)	2.2	3.6	1.8
Oklahoma	I	58	6.4 (2.1)	0.6 (0.2)	1.9	8.6	41.4
Texas	I	56	3.9 (1.1)	1.4 (0.3)	2.2	1.7	8.9
Flyway total	I	283	4.2 (0.6)	0.8 (0.1)	1.9	4.9	32.9
North Dakota	A	17	7.9 (3.0)	3.3 (1.1)	4.8	11.8	0.0
Nebraska	A	21	5.1 (1.1)	2.3 (1.5)	3.9	0.0	0.0
Colorado	A	21	4.1 (0.8)	3.7 (0.9)	4.0	0.0	4.8
Oklahoma	A	20	6.1 (2.2)	2.3 (0.7)	3.6	15.0	5.0
Texas	A	16	6.3 (1.7)	3.0 (2.9)	9.2	0.0	0.0
Flyway total	A	95	5.8 (0.8)	2.7 (0.5)	4.3	5.3	2.1

Table 2. *Continued.*

Species, flyway, and State	Life stage	Sample size	Statistic			Percent wings with	
			Mean (±SE)	Median (±SE)	Interquartile range	>20.0 ppm	<0.5 ppm
Pacific							
Idaho	I	54	10.4 (2.4)	1.2 (0.7)	5.2	16.7	13.0
Oregon	I	56	21.5 (6.9)	0.9 (1.1)	7.9	17.9	37.5
California	I	54	7.4 (1.8)	2.2 (1.1)	7.9	9.3	16.7
Utah	I	54	35.9 (9.5)	6.2 (4.9)	36.3	31.5	1.9
Colorado	I	57	3.1 (0.7)	1.3 (0.2)	1.6	3.5	15.8
Flyway total	I	275	15.6 (2.5)	1.4 (0.4)	7.9	15.6	17.1
Idaho	A	20	6.6 (2.6)	2.5 (1.3)	6.0	10.0	5.0
Oregon	A	21	9.5 (4.7)	2.5 (0.6)	2.8	14.3	4.8
California	A	19	20.7 (6.0)	9.7 (6.4)	29.2	42.1	0.0
Utah	A	19	25.9 (8.1)	7.4 (11.7)	31.4	26.3	0.0
Colorado	A	21	8.9 (2.7)	3.8 (0.9)	4.4	19.0	0.0
Flyway total	A	100	14.0 (2.4)	3.8 (0.9)	14.0	22.0	2.0
Mallard total	I	1,461	9.9 (0.4)	1.1 (0.1)	7.9	13.2	15.4
Mallard total	A	450	12.3 (1.0)	4.4 (0.4)	12.8	19.1	1.6
BLACK DUCKS							
Atlantic							
Maine	I	56	5.2 (1.2)	2.0 (0.4)	3.3	5.4	1.8
New York	I	55	5.4 (1.0)	2.8 (0.5)	3.7	7.3	1.8
Massachusetts	I	65	7.2 (1.3)	3.8 (0.5)	4.1	7.7	0.0
Maryland	I	55	11.4 (2.2)	5.3 (1.2)	10.0	12.7	0.0
Virginia	I	39	13.2 (3.5)	5.7 (1.8)	11.8	17.9	0.0
Flyway total	I	270	8.1 (0.8)	3.7 (0.3)	5.0	9.6	0.7
Maine	A	22	7.4 (2.0)	3.1 (1.5)	5.7	9.1	0.0
Massachusetts	A	23	7.9 (1.3)	5.4 (1.2)	6.1	8.7	0.0
Flyway total	A	45	7.7 (1.2)	4.7 (0.9)	6.2	8.9	0.0
PINTAILS							
Central							
North and South Dakota	I	67	2.3 (1.1)	0.6 (0.1)	0.5	3.0	43.3
Kansas-Colorado	I	61	4.5 (1.2)	0.8 (0.1)	1.2	6.6	24.6
Texas-Oklahoma	I	63	3.1 (1.1)	1.0 (0.1)	1.2	3.2	14.3
Flyway total	I	191	3.3 (0.7)	0.7 (0.1)	1.1	4.1	27.7
North Dakota	A	22	4.3 (1.8)	2.1 (0.5)	2.6	4.5	13.6
Kansas	A	21	8.6 (2.1)	4.3 (2.3)	9.3	9.5	0.0
Texas	A	22	9.2 (2.3)	5.3 (3.6)	5.6	22.7	0.0
Flyway total	A	65	7.4 (1.2)	3.3 (0.7)	5.8	12.3	4.6
Pacific							
Oregon	I	66	13.5 (4.1)	0.4 (0.5)	3.9	16.7	50.0
California	I	56	11.3 (5.2)	0.9 (0.4)	2.7	8.9	33.9
Utah	I	61	6.6 (2.2)	1.1 (0.4)	3.4	9.8	24.6
Arizona-Nevada	I	63	2.7 (1.6)	0.3 (0.0)	0.5	1.6	69.8
Flyway total	I	246	8.5 (1.8)	0.6 (0.1)	2.5	9.3	45.1
Oregon	A	21	10.1 (3.2)	3.5 (2.7)	13.3	19.0	23.8
California	A	24	6.0 (1.8)	2.2 (1.2)	6.0	12.5	12.5
Utah	A	19	7.3 (3.3)	2.5 (1.1)	3.0	10.5	0.0
Arizona-Nevada	A	22	3.7 (0.7)	2.3 (1.0)	4.4	0.0	9.1
Flyway total	A	86	6.7 (1.2)	2.5 (0.5)	5.1	10.5	11.6
Pintail total	I	437	6.2 (1.0)	0.7 (0.1)	1.6	7.1	37.5
Pintail total	A	151	7.0 (0.9)	2.7 (0.4)	5.7	11.3	8.6

Table 2. *Continued.*

Species, flyway, and State	Life stage	Sample size	Statistic			Percent wings with	
			Mean (±SE)	Median (±SE)	Interquartile range	>20.0 ppm	<0.5 ppm
MOTTLED DUCKS							
Atlantic							
Florida	I	60	37.1 (9.2)	9.7 (4.3)	34.2	36.7	1.7
Mississippi							
Louisiana	I	44	26.7 (4.5)	15.5 (5.1)	32.8	45.4	0.0
Central							
Texas	I	55	54.4 (9.2)	18.7 (10.5)	73.5	49.1	0.0
Atlantic							
Florida	A	22	45.9 (14.7)	16.8 (11.0)	43.3	45.4	0.0
Mississippi							
Louisiana	A	15	36.8 (12.8)	7.9 (19.2)	48.8	40.0	0.0
Central							
Texas	A	32	55.4 (14.0)	16.2 (12.4)	69.7	43.8	0.0
Mottled duck total	I	159	40.2 (4.9)	15.1 (3.3)	48.2	43.4	0.6
Mottled duck total	A	69	48.3 (8.4)	16.2 (5.9)	60.5	43.5	0.0
CANVASBACKS							
Mississippi	I	29	8.2 (4.2)	0.6 (0.6)	2.6	6.9	24.1
Central	I	21	2.3 (0.7)	0.3 (0.8)	2.4	0.0	52.4
Pacific	I	59	9.4 (2.6)	1.0 (1.2)	9.3	10.2	25.4
Mississippi	A	24	15.4 (3.2)	9.0 (3.7)	20.4	29.2	0.0
Central	A	11	12.2 (2.7)	9.6 (2.6)	3.9	9.1	0.0
Pacific	A	21	20.8 (5.4)	9.4 (5.6)	24.9	33.3	0.0
Canvasback total	I	109	7.7 (1.8)	0.9 (0.5)	6.1	7.3	30.3
Canvasback total	A	56	16.8 (2.5)	9.5 (2.5)	19.1	26.8	0.0
REDHEADS							
Central	I	33	16.5 (5.9)	0.6 (3.2)	17.6	24.2	48.5
Pacific	I	62	27.2 (9.1)	5.0 (1.5)	11.0	17.7	6.5
Central	A	16	15.3 (3.8)	8.5 (5.3)	21.9	31.2	0.0
Pacific	A	35	30.2 (7.1)	12.3 (4.4)	26.9	37.1	0.0
Redhead total	I	95	23.5 (6.3)	4.0 (1.2)	15.4	20.0	21.1
Redhead total	A	51	25.5 (5.1)	9.9 (3.3)	25.3	35.3	0.0
LESSER SCAUP							
Atlantic	I	56	2.8 (0.5)	1.3 (0.3)	2.3	0.0	12.5
Mississippi	I	53	1.8 (0.5)	0.7 (0.1)	1.0	0.0	28.3
Minnesota	I	57	2.6 (0.9)	0.6 (0.1)	0.8	1.8	38.6
Central	I	59	1.0 (0.1)	0.7 (0.1)	0.9	0.0	39.0
Pacific	I	39	0.8 (0.2)	0.3 (0.0)	0.0	0.0	76.9
Atlantic	A	21	2.8 (0.4)	2.7 (0.6)	3.0	0.0	0.0
Mississippi	A	23	1.8 (0.4)	1.3 (0.2)	1.1	0.0	13.0
Minnesota	A	20	2.4 (0.7)	1.1 (0.6)	1.3	0.0	5.0
Central	A	20	1.3 (0.2)	1.1 (0.2)	0.6	0.0	0.0
Pacific	A	19	5.7 (2.2)	2.4 (1.5)	6.5	5.3	10.5
Scaup total	I	264	1.9 (0.3)	0.7 (0.1)	1.1	0.4	36.7
Scaup total	A	103	2.8 (0.5)	1.4 (0.2)	1.9	1.0	5.8

Table 3. *Residues of lead (ppm, dry weight) in wing bones of immature mallards from Alaska and different zones of Pacific Flyway States, 1973.*

State	Zone	Sample size	Statistic			Percent wings with	
			Mean (±SE)	Median (±SE)	Interquartile range	>20.0 ppm lead	<0.5 ppm lead
Alaska	—	66	5.8 (2.2)	0.3 (0.2)	2.0	7.6	54.5
Washington	East	56	8.4 (3.0)	0.9 (0.3)	2.5	14.3	16.1
Washington	West	62	23.6 (6.1)	2.5 (2.0)	20.8	25.8	32.3
Oregon	Columbia River	37	44.7 (11.2)	10.1 (7.9)	46.6	43.2	32.4
Oregon	Remainder	60	15.3 (5.0)	1.3 (1.4)	12.7	20.0	23.3
California	Merced	62	15.0 (2.8)	4.1 (1.5)	22.2	25.8	1.6
California	Sacramento	63	28.4 (8.4)	1.8 (2.1)	17.6	23.8	22.2
California	Remainder	64	24.6 (6.2)	7.4 (2.5)	20.4	26.6	6.3

(mostly northeastern California and San Francisco Bay area)—contained similar proportions of wing bones with more than 20.0 ppm of lead. Differences did occur in the median values, however, which were lowest in birds from the Sacramento area and highest in those from the remainder of the State.

Wing bones of 66 immature mallards collected in Alaska during 1973 had a low incidence of lead, although 7.6% of them contained more than 20.0 ppm (Table 3). More than 50% of the sample contained only trace amounts (<0.5 ppm).

Cumulative frequency distributions show the dispersion of lead residues in samples with less than 0.5 ppm to samples with 20.0 ppm and provide a useful method for analyzing lead occurrence in a sample of wing bones. The distributions of lead residues for representative State samples of immature mallards are illustrated in Fig. 5, species differences for all immature waterfowl in the survey in Fig. 6, and differences among flyways for all immature mallards in Fig. 7. The value on the ordinate of these graphs represents the sum of all the probabilities up to and including the class in question. The shape of the graph indicates the distribution of lead residues for the sample. Lines that have a low intercept on the left ordinate, approach linearity, and have slight to moderate slope (e.g., immature mallards from Massachusetts, Fig. 5) indicate samples where most birds had ingested lead. Samples with this characteristic reflect a background source or sources of lead in addition to lead shot and the two sources cannot be isolated. In contrast, lines that have a high left ordinate intercept, and an initial steep slope, and then a break to a more gradual slope represent populations with low background levels (e.g., immature mallards from Nebraska, Fig. 5). Graphs for birds with moderate exposure to background lead sources are intermediate (e.g., immature mallards from California and Indiana, Fig. 5).

Most lines intercept the right ordinate at a point between 85 and 95%, which indicates little variation in the proportions of the samples containing elevated lead levels, regardless of the presence or absence of

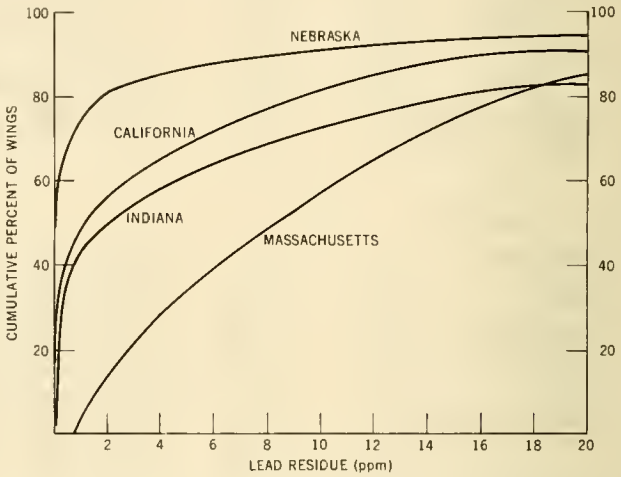

Fig. 5. Cumulative frequency distributions of lead in wing bones of immature mallards from Massachusetts, Indiana, Nebraska, and California.

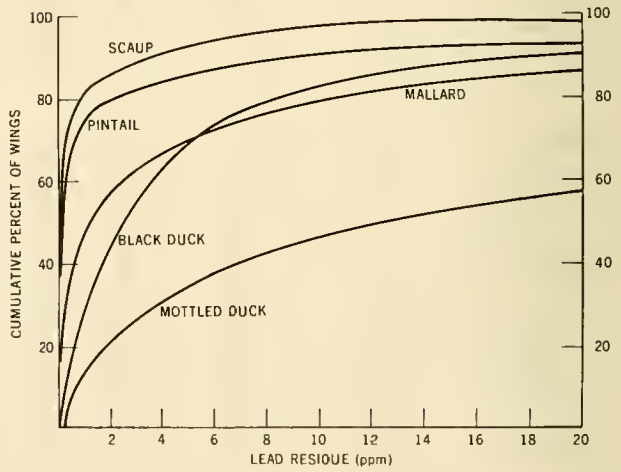

Fig. 6. Cumulative frequency distributions showing species differences in lead residues in wing bones of all immature mallards, black ducks, mottled ducks, pintails, and scaup.

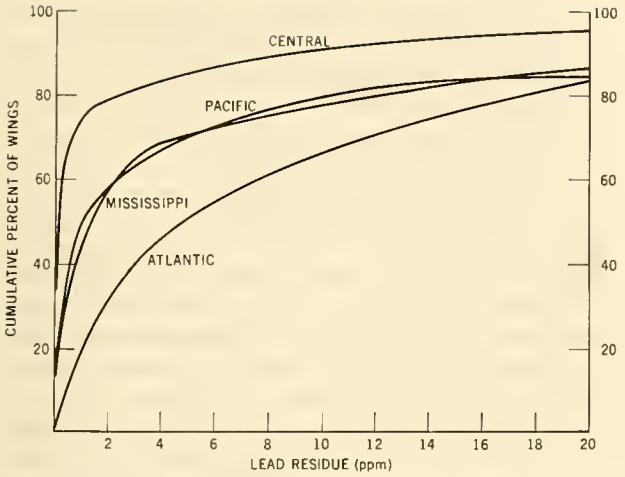

Fig. 7. Cumulative frequency distributions showing differences in lead residues for immature mallards from different flyways.

background sources. Mottled ducks, for which the right ordinate intercept is at 57% (Fig. 6), are an obvious exception.

Discussion

Analysis of lead in wing bones provides an assessment of the exposure of waterfowl to lead, yet several biases result from the method and timing of sample collection. The wings were supplied by hunters who shot the birds during the regular waterfowl season. Inasmuch as ducks afflicted with lead poisoning are more likely to be bagged by hunters than are healthy birds (Bellrose 1959), a disproportionate number of birds suffering from lead poisoning may be represented in our samples. However, two factors bias the data in the opposite direction: (1) gizzard collections indicate that shot ingestion rates increase during the course of the hunting season, and a very high proportion of the wings received from hunters are from ducks bagged during the first 2 weeks of the season—presumably before extensive shot ingestion has occurred; and (2) no wings were collected in winter or spring after the hunting season, when lead poisoning mortalities among waterfowl are frequently observed.

Lead residues in soft tissues such as blood, liver, and kidney indicate current exposure—that is, lead that is circulating in the system when the bird was collected. Bone, however, is a storage site for lead, and residues in bone indicate the animals' exposure to this element over a long period of time. Uptake of lead by bone is rapid, and loss slow. Residues in bone reflect both acute and chronic exposure to lead from all sources. Hence, an elevated level of lead in the bone may not necessarily reflect ingestion of lead shot. Bones of birds eating foods containing moderate or high amounts of lead over a long period of time may accumulate high residues. Ingestion of a lead shot, however, may result in elevated levels in the bones almost immediately (unpublished data, Patuxent Wildlife Research Center [PWRC] 1974).

Bones of waterfowl dying from lead poisoning generally contain high concentrations of lead—often over 100 ppm (Longcore et al. 1974*b*). For example, wing bones of lesser scaup found dead or dying of lead poisoning at Rice Lake, Illinois, in 1972 contained from 12 to 138 ppm of lead (Anderson 1975). Similarly, lead residues in wing bones of 20 whistling swans (*Olor columbianus*) found dead at Mattamuskeet National Wildlife Refuge in 1973 ranged from 13 to 91 ppm (unpublished data, PWRC, 1974). In contrast, tibiae of seven species of waterfowl with no known history of lead exposure contained from 2 to 13 ppm of lead (Bagley and Locke 1967).

The uptake of lead in waterfowl wing bones has been evaluated in experimental studies. Wing bones of drake mallards fed a corn diet and dosed with one No. 4 lead shot accumulated lead in an almost linear fashion during a 21-day period (unpublished data, PWRC, 1974). The lead concentrations rose within 24 h after the birds were dosed, and averaged 110 ppm after 21 days. In a second study, 5 weeks after 6-month-old male mallards fed a commercially prepared mash were dosed with one No. 4 lead shot, the wing bones contained an average of 10 ppm of lead as compared with about 4 ppm in control birds (Finley et al. 1976*a*). These studies show that the uptake of lead in mallard wing bones can be rapid, but that the diet—here corn vs. a commercial mash—has an important influence on rate of uptake of lead by bone. The ranges of elevated lead residues accumulating in wing bones of mallards from these two studies approximated the ranges that occur in many wild waterfowl.

Other studies have shown the relative permanence of lead residues in bone. Two Canada geese (*Branta canadensis*) exposed to lead shot, then maintained in captivity for 1 year with no further exposure to lead, had 30 and 38 ppm of lead in their leg bones (Adler 1944). Leg bones of four geese that either died of lead poisoning or were sacrificed soon after exposure to lead shot contained an average of 83 ppm of lead. In another study, lead residues in wing bones of mallards did not decline appreciably during a 30-week period after the birds had been dosed with one No. 4 lead shot (unpublished data, PWRC, 1974). They contained an average of 21, 36, and 36 ppm of lead at 6, 18, and 30 weeks, respectively, after exposure. These studies indicate (1) that an immature bird (4-8 months old when shot) with elevated levels of lead in its wing bones may have been exposed to lead at any time during its life, and (2) an

adult bird (more than 1 year old) with elevated levels of lead in its wing bones may have been exposed to lead during the current or previous years.

A number of important factors that influence the uptake of lead by bone are briefly discussed below.

Species

Redheads and lesser scaup that were shown to have similar levels of ingested shot (Bellrose 1959) had accumulated vastly different concentrations of lead in their wing bones: those in redheads were high, whereas those in scaup were low (only trace amounts). Species differences in diet may influence the uptake of lead and contribute to the observed differences among species in the rate of accumulation of lead residues in bone.

Age

Immature birds that are still depositing calcium in their bones could deposit more lead than adults with an equivalent exposure. Immature lesser scaup that died of lead poisoning contained higher lead residues than did adults, suggesting that immatures either deposited lead in their bones at a faster rate or that they were more resistant than adults to lead poisoning (Anderson 1975). In dosing studies with mallards, adults were more severely affected by lead shot (Jordan and Bellrose 1951).

Although ingestion rates of lead shot may not differ significantly between adults and immatures, susceptibility to the effects of lead and later accumulation of lead in bone may differ between age groups. Moreover, elevated lead residues in bones of adults may represent chronic exposure to lead from other sources, as mentioned earlier, or exposure to shot during previous seasons. For these reasons, immatures and adults should be considered separately in surveys of lead in waterfowl wing bones.

Sex

The frequency of occurrence of shot in gizzards of males and females did not differ significantly in most samples of ducks and geese collected from national wildlife refuges in 1974 (White and Stendell 1977) and 1975 (unpublished data, Migratory Bird and Habitat Research Laboratory [MBHRL], 1976). Experimental studies have shown, however, that females may be more susceptible to lead poisoning than males: Bellrose (1959) reported that females dosed with lead shot suffered higher mortality than males, except during a brief period before the breeding season. In contrast, Longcore et al. (1974*b*) found no difference in mortality rates between male and female mallards dosed with eight No. 6 lead shot (at this level of dosing, however, mortality of birds of both sexes was high).

Accumulation of lead in tissues does not differ between the sexes except during the breeding season when females accumulate higher residues than males. No sex differences occurred in lead concentrations in the blood of ducks dosed with lead shot among mallards (Finley et al. 1976*a*) or wild canvasbacks (Dieter et al. 1976). Similarly, there were no significant sex differences in wing bone lead residues in lesser scaup that died of lead poisoning (Anderson 1975) or of four species of waterfowl collected at national wildlife refuges during 1974 (White and Stendell 1977). In mallards dosed with one No. 4 lead shot the accumulation of lead in the wing bones was higher in females than in males (Finley et al. 1976*a*). However, that study was done with breeding birds, and the excessively high residues in females were related to medullary bone formation before and during egg laying. In a second study, the accumulation of lead in the wing bones of mallards dosed with one No. 4 lead shot averaged 180 ppm in laying birds and only 25 ppm in nonlayers (Finley and Dieter 1978). These studies suggest that sex differences in accumulation of lead in bone are not significant except perhaps during the breeding season, and need not be considered in fall and winter surveys of lead in waterfowl wing bones.

Diet

The kind of food consumed by waterfowl exerts an important influence on the toxicity of lead. Experimental studies have shown that waterfowl feeding exclusively on grain diets, such as corn, are more susceptible to lead poisoning than are waterfowl feeding on more varied diets. For example, mallards fed mixed grains or whole or cracked corn and given three or eight No. 6 lead shot suffered from 46 to 93% mortality (unpublished data, MBHRL); for birds fed a commercial duck ration, however, only 3% of those given eight shot and no birds given three shot died. Canada geese on a mixed diet of whole corn and a commercially prepared duck food were severely affected by a dose of two No. 4 lead pellets as long as they continued to feed on corn, but all except one recovered when they were shifted exclusively to the commercial duck food (Jordan and Bellrose 1951).

Nutritional factors have an important influence on the absorption of lead from the gut, later transfer to soft tissues, and storage in bone. Drake mallards fed exclusively a corn or rice diet and given one to five No. 4 lead shot accumulated about 10 times more lead than did mallards fed a commercial duck ration (unpublished data, PWRC, 1974). In addition, the nature

of the grit ingested by waterfowl influences shot erosion and retention, which in turn affects mortality of waterfowl from lead poisoning (Longcore et al. 1974*a*).

Lead from Sources Other than Ingested Shot

Birds given lead in forms other than shot may accumulate elevated levels of lead in their wing bones. High levels of lead accumulated in bone as a result of daily oral administration of 6 to 12 mg of lead nitrate per kilogram of body weight to mallards fed cracked corn and wheat (Coburn et al. 1951). In another study, Finley et al. (1976*b*) dosed first-year mallards fed a commercial breeder mash diet with either 1, 5, or 25 ppm of lead as lead nitrate; however, a steady diet containing these concentrations of lead for 12 weeks did not result in elevated levels of lead in the wing bones of the birds. Thus, continuous, low-level ingestion of lead by mallards does not necessarily result in elevated levels in the wing bones. As in lead shot ingestion, the nature of the diet has an important influence on the rate of accumulation of lead.

Seasonal Variation

In samples of gizzards collected at national wildlife refuges during 1974, the incidence of shot in gizzards increased as the hunting season progressed (White and Stendell 1977). This increase was paralleled by increases in lead residues in wing bones. Consequently, in surveys of lead in waterfowl wing bones, timing of the collection should be an important consideration.

Number of Shot Ingested

Lead shot occurred in 6.7% of all duck gizzards examined by Bellrose (1959). In that survey 65% of the gizzards containing shot held only one pellet and 15% held two. For four species of waterfowl collected on national wildlife refuges, 61% of the gizzards with ingested shot contained only one pellet (White and Stendell 1977).

No simple linear relationship occurred between number of shot ingested and lead residues in wing bones of mallards fed corn or rice diets and dosed with one to five No. 4 lead shot (unpublished data, PWRC, 1974). Birds given one shot had the least lead in their wing bones, and those given two or five shot had the most. Birds given three or four shot contained intermediate amounts. Anderson (1975) found a significant relationship between number of shot in gizzards and lead levels in bone of lesser scaup that died of lead poisoning at Rice Lake, Illinois. Mean and median lead levels in wing bones of mallards and pintails increased as number of shot in gizzards increased (unpublished data, PWRC, 1974); for example, residues averaged 11 ppm (median, 2.4) in birds whose gizzards contained no shot and 69 ppm (median, 46.8) in birds whose gizzards contained two or more.

Shot Retention

Lead shot may be voided by waterfowl soon after ingestion or retained in the gizzard for varying periods of time up to 6 weeks (by then it is generally completely eroded). The average time of retention for mallards dosed with No. 6 lead shot and showing no obvious signs of lead poisoning was 18 days (Jordan and Bellrose 1951). If the birds showed signs of lead poisoning, the shot was retained longer. In four experimental studies conducted at the Patuxent Wildlife Research Center with mallards dosed with lead shot, 163 of 174 birds (94%) retained the shot for at least 1 week (Longcore et al. 1974*b*; Finley et al. 1976*a*; Finley and Dieter 1978; and unpublished data, PWRC, 1974). Some captive mallards severely affected with lead poisoning recovered after voiding the shot (Jordan and Bellrose 1951). Most mallards that ingest lead shot either die or recover within 4 weeks.

The period of time the shot has been retained in the gizzard when the bird is collected influences the lead level in the bone. Lead concentrations are low in wing bones of wild birds collected soon after shot is ingested (assuming they have had no previous exposure to lead) but are higher in birds collected after the shot has been retained for a time or has been completely eroded. Consequently there is generally no relationship between occurrence of shot in the gizzard and lead residues in the wing bones of individual birds. On the one hand, ingested lead may be completely eroded or passed from the digestive system before the bird is collected, resulting in high wing-bone lead but no shot in the gizzard; on the other hand, a bird collected soon after ingesting shot would have shot in the gizzard but low wing-bone lead. About 11% of 1,153 mallards found dead or moribund in lead poisoning die-offs in six States during 1938-55 had no shot in their gizzards (Bellrose 1959). For samples of waterfowl collected from national wildlife refuges, no predictable relationship occurred between the number of lead shot in the gizzard of an individual bird and the lead level in its wing bones (White and Stendell 1977). There was, however, a significant relationship between lead residues in wings and lead shot in the gizzard when the data were examined on a population basis. The lead burden of various populations, as measured by lead in the wing bones (median lead level or percent of sample with more than 20.0 ppm), varied positively with the

incidence of lead pellets in the gizzards taken from these populations.

Conclusions

The number of waterfowl that ingest lead pellets and later die from lead poisoning is difficult to estimate. Large-scale outbreaks of the disease are frequently reported, but the number of birds that die unobserved is not known. Moreover, the extent and severity of sublethal effects need further study. Direct and indirect measures are used to determine lead exposure and toxicity, although none provide sufficient documentation of the severity of the problem or are feasible on a nationwide basis. Direct observation of dead birds in the field, with supporting diagnosis of lead poisoning, provides the best evidence, but this is not practical or possible on a large scale. The occurrence of lead pellets in gizzards indicates current ingestion rates, but because of the complexity of factors influencing lead toxicity, it does not necessarily indicate mortality or the extent of sublethal effects. Residues in soft tissues such as liver, kidney, or blood indicate the amount of lead currently circulating in the bird and provide the best indication of acute toxicity or potential sublethal effects. The residues, however, do not indicate the source of the lead. Analysis of lead in wing bones provides an indirect assessment of a bird's exposure to lead and may be used to assess lead burdens arising from acute or chronic exposure and indicates geographic patterns of lead exposure. In this procedure the extent of waterfowl mortality resulting from lead poisoning is not estimated.

The 1972-73 wing-bone survey demonstrated that lead occurs in the bodies of some immature ducks at levels that indicate high exposure over an interval of only a few months. Information now available suggests that much of lead found in the wing bones originated from ingested lead pellets.

The survey does provide a base line for lead levels in selected species and this base is essential for evaluating the potentially beneficial effects on populations of the conversion from lead to steel shot for waterfowl hunting. As nontoxic shot continues to replace lead shot for waterfowl hunting, the lead burdens in waterfowl should decline. Analysis of lead residues in waterfowl wing bones is a valuable tool for monitoring this decline.

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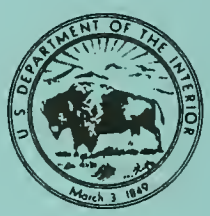

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